Channel Response to Changes in the Runoff Regime along the Walnut Gulch Channel

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ABSTRACT

Geomorphic adjustment of the Walnut Gulch channel from 1935 to 2005 was evaluated with respect to planform and channel cross section geometry based on air photo interpretations and field measurements coupled with runoff records. In 1935, Walnut Gulch was a wide, sand bed channel with extensive braiding in the lower reaches, and little in-channel vegetation. These physical characteristics are consistent with conveyance of large magnitude flows that minimized vegetation establishment. These channel characteristics are evident through the 1960s; however, by 1980 the primary channel flow path had inset with braided flow in the lower reach, and vegetation had established on sediment deposits. From 1935 to 1974 the area occupied by vegetation decreased 7%. From 1974 to 2005, the area occupied by vegetation increased 79%. In addition, adjustments to cross section geometry have resulted in a general increase in hydraulic radius of the primary flow path(s) and associated decrease in shear forces on the channel. These geomorphic adjustments are driven by a temporal change in measured runoff characteristics. From 1974 through 2000, there was a decrease in the number and magnitude of measured runoff events in comparison with runoff measured from the late 1950s through 1973.

INTRODUCTION

Surface flow regimes in semi-arid and arid climates are highly variable in frequency, magnitude, and duration. The variability of these factors allow for the persistence of effects from high-magnitude floods and can also provide an opportunity for vegetation to establish in the channel. Long term trends in rainfall and runoff patterns can affect both sediment storage and vegetation in the channel. The response of alluvial channels to changes in rainfall and runoff regimes have the potential to affect water supply through changing water storage and water quality by altering sediment delivery. This study is a compilation and review of historical and present data sets to ascertain geometric and spatial changes and trends in the channel and to evaluate how changing channel geometry affects flow hydraulics and shear forces.

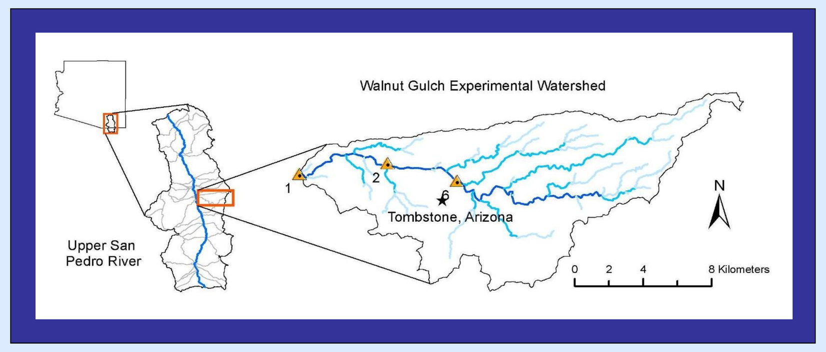


Figure 1. Location of Walnut Gulch Experimental Watershed and the three supercritical - flow measuring flumes situated in the main channel study area.

STUDY SITE

Rainfall and Runoff:

- Average annual precipitation ranges from 300 mm (11.8 in) at the lower end (1275 m) of the watershed to 340 mm (13.4 in) at the upper end (1585 m).
- Precipitation and runoff are characterized by extreme variability, both interannually and intrannually.
- Summer precipitation resulting from convective thunderstorms accounts for approximately 2/3 of the annual total and results in nearly all of the surface runoff.
- Runoff in the ephemeral channels is characterized by reduced flow volumes and peak runoff rates in the downstream direction due to transmission losses.

Channel Characteristics:

- Walnut Gulch channel is an ephemeral, alluvial channel with coarse sand bed material draining 58 sq. mi (150 sq. km) of the WGEW
- The study reach within the lower Walnut Gulch channel spans 11.4 km from Flume 6 to the watershed outlet at Flume 1 (Figure 1 and Figure 2). The average channel slope is 1% and the average channel width is 45 m.
- Geologic and anthropomorphic features control the width and form of Walnut Gulch channel at several sections along the channel:
  - Geologic features include: conglomerates, granodiorite, and fault lines
  - Anthropomorphic features include: flumes, road crossings, railroad bridges, a sewage treatment facility, and aggregate borrow pits.

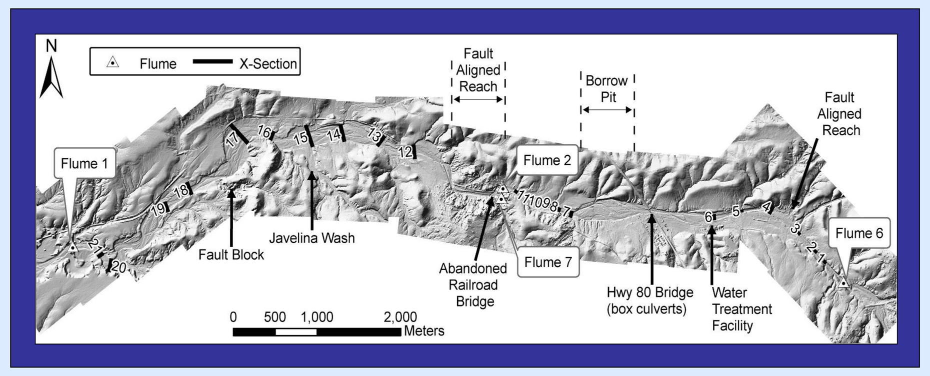


Figure 2. Hillshade model of study reach indicating cross section locations in relation to geologic and anthropomorphic features.

METHODS

- Detailed data collection to describe the morphology of Walnut Gulch began in the 1950s prior to the construction of the large supercritical flumes. Ground based channel cross-section measurements (using a level and stadia rod) were surveyed in 1961 between Flumes 1 and 2 and in 1965 between Flumes 2 and 6. Repeat surveys were conducted in 2003 using a Trimble Real Time Kinematic (RTK) GPS.
- Aerial photo sets for the years 1935, 1974, and 2005 were used in this analysis. A 1-meter LIDAR surface model was produced in 2003 for the WGEW that provides additional topographic detail for the study reach. The three photosets were digitized onscreen to delineate channel vegetation. Digital terrain models of the channel area were generated from the 1974 and 2005 photo datasets. Cross section measurements coincident with the historical cross sections were extracted from digital elevation models generated using standard air photo techniques.
- Changes in channel cross-section geometry were evaluated based on the 2 and 10-year peak discharge flow rates. A standard form of Manning's equation implemented using WinXSPRO (Hardy et al. 2004) was used to calculate flow velocities.

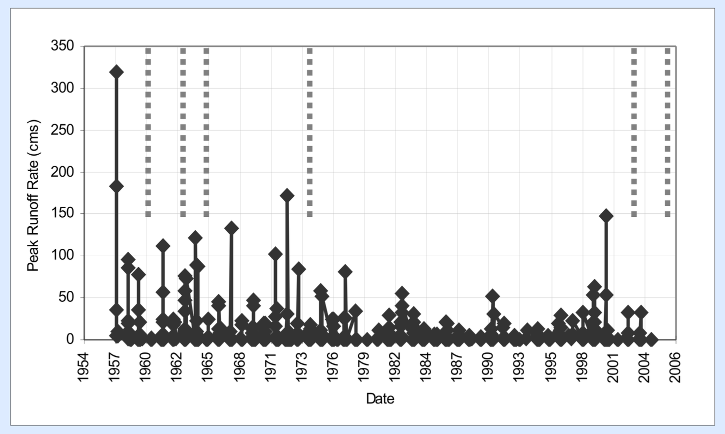


Figure 3. Event peak discharge rates recorded at Flume 1 with years of channel measurement indicated by dashed vertical lines.

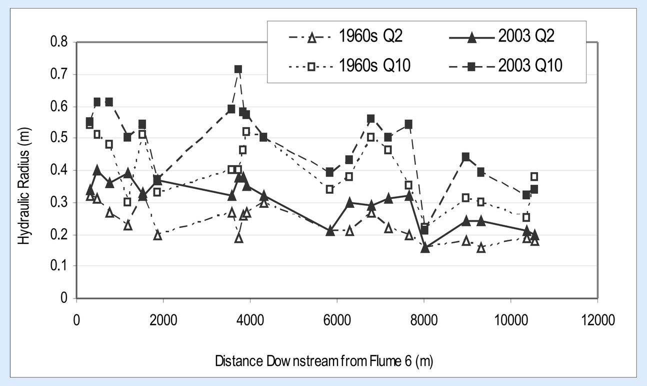


Figure 5. Variation in hydraulic radius with distance from Flume 6 computed for 2 and 10-year return period peak flows through 21 cross-sections measured over time.

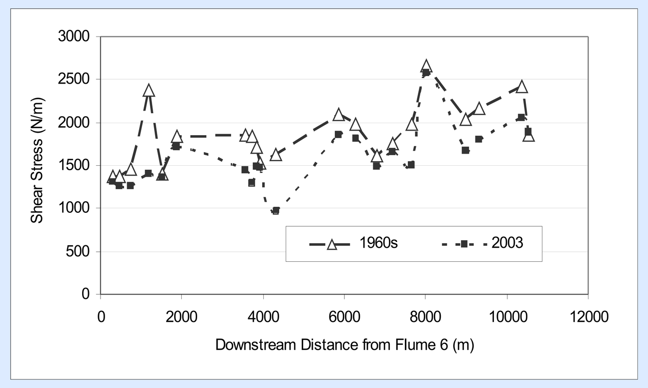


Figure 6. Variation in total shear stress with distance from Flume 6 computed for the 10-year return period flow through 21 cross-sections measured over time.

RESULTS

Runoff Trends (see Figure 3)

- **1961 – 1974**
  - -Flume 1: **Five** flow events exceeded the **10-year** return period peak flow and **20** flow events exceeded the **2-year** return period peak flow
  - -Flume 6: **Two** flow events exceeded the **10-year** return period peak flow and **13** flow events exceeded the **2-year** return period peak flow
- **1974 – 2005**
  - -Flume 1: **One** flow event exceeded the **10-year** return period peak flow and **20** flow events exceeded the **2-year** return period peak flow
  - -Flume 6: **One** flow event exceeded the **10-year** return period peak flow and **19** flow events exceeded the **2-year** return period peak flow

Planform Changes:

- There has been an increase in the number and extent of vegetation islands in the channel as well as encroachment of vegetation into the channel along the channel banks (Figures 4a-d).
- Between 1935 and 1974 there was a decrease of 7% in the spatial extent of channel vegetation.
- Between 1974 and 2005 there was an increase of 79% in the spatial extent of channel vegetation.

Geometric Changes:

- Channel reaches which are laterally constrained due to geologic features have either downcut across the channel or incised within the channel (Figure 4d)
- Channel reaches without lateral constraints (generally found from Flume 2 to 1) have developed a single or multiple inset channel(s) (Figure 4c)
- Most flows equal to or less than the 10-year return period peak flow and even the 25-year return period peak flow in some sections are now conveyed and contained through the inset channel.
- In general there has been an increase in the hydraulic radius of channel cross-sections from the 1960s to 2003 (Figure 5 and Table 1).

Table 1. Representative cross-sections with corresponding hydraulic radius (R) and total shear stress (Shear) calculated for each respective time period.

X-Section	1960s R (m)	1960s Shear (N/m)	1974 R (m)	1974 Shear (N/m)	2003 R (m)	2003 Shear (N/m)
	Cross-Sections Constrained Laterally					
1	0.5	1380	N/A	N/A	0.6	1300
3	0.5	1460	N/A	N/A	0.6	1250
16	0.4	1990	0.4	2090	0.5	1500
	Cross-Sections with Lateral Migration					
4	0.3	2380	0.4	2710	0.5	1410
8	0.4	1850	0.4	1730	0.7	1290
19	0.3	2160	0.3	2310	0.4	1800

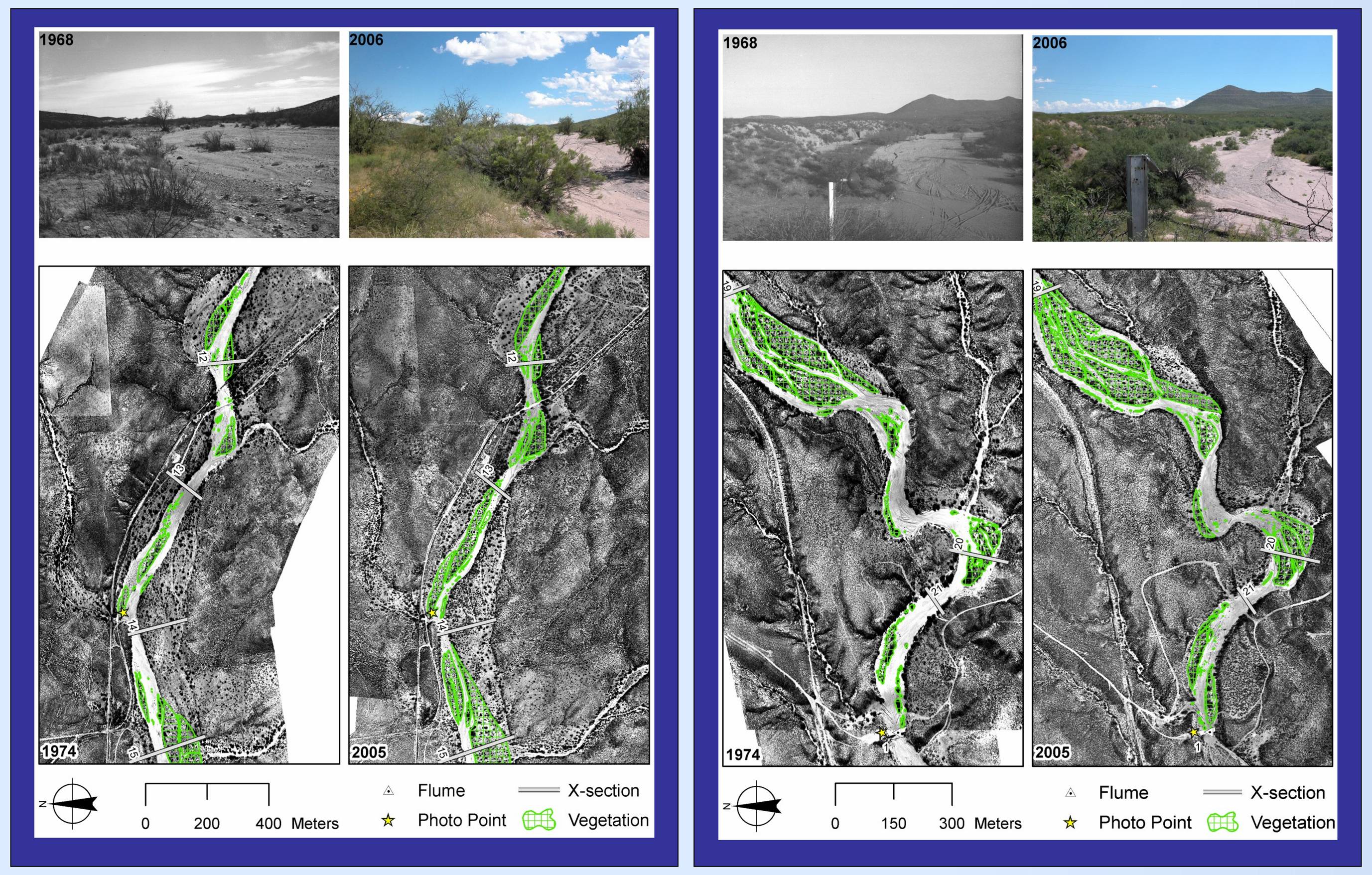
CONCLUSIONS

The geomorphic characteristics of the Walnut Gulch channel are controlled by the complex interaction among sediment and runoff volume, peak rates, and duration, with additional controls exerted by local geology, manmade structures, and vegetation.

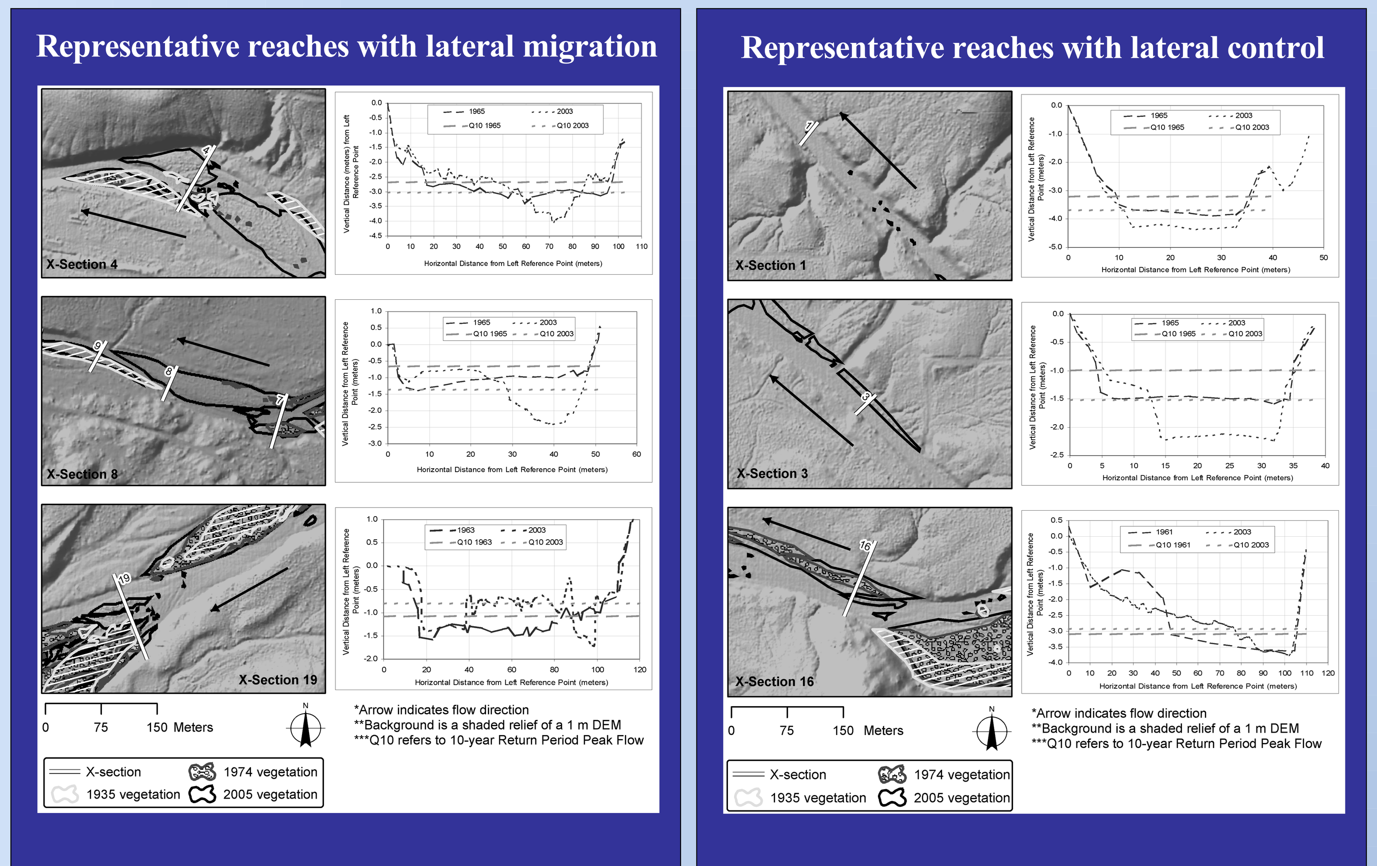
A trend towards fewer higher-magnitude flow events since 1974 has influenced in-channel vegetation establishment and channel geometry. The development of inset or incised flow channels since 1974 increases the efficiency of the flow by decreasing resistance from bed friction. The decrease in resistance can be calculated as the total shear force that is exerted on the channel bed and banks. In general there has been a decrease in total shear force since the 1960s (Figure 6).

The vegetation increase may be a response to a combination of increased available moisture during non-summer months (Nichols et al. 2002) and fewer large magnitude flow events during the summer months. Established vegetation can control flow paths as well as contribute to channel roughness. If lateral migration is restricted by vegetation, sediment supply will be satisfied by eroding the channel bottom. In the event that the incised channel section is overtopped, vegetation may further reduce the flow energy, induce deposition, and increase water storage.

Although the trends identified may represent short term fluctuations in rainfall and runoff, an improved understanding of the relationships among precipitation, runoff, and channel vegetation establishment is important for understanding the potential impacts of larger-scale climate changes on water quality and quantity.



Figures 4a and 4b. Two channel reach locations showing planform and oblique channel views from the 1960/70 and 2005/06 period. The oblique photo locations are indicated on the planform map and are looking east (upstream) in both photo sets.



Figures 4c and 4d. Six representative cross sections showing planform and 3-dimensional x-section views. The 10-year return period peak flow is indicated in each cross section. Arrow indicates flow direction.

SELECTED REFERENCES

Hardy, T., P. Panja, and D.Mathias (2004). WinXSPRO, A channel cross section analyzer, User's Manual, Version 3.0. Gen. Tech. Rep. RMRS-GTR-147. USDA, Forest Service, Rocky Mountain Research Station, Ft. Collins, CO. 95pp.

Nichols, M.H., Renard, K.G., and Osborn, H.B. (2002). Precipitation changes from 1956-1996 on the USDA-ARS Walnut Gulch Experimental Watershed. J. Am. Water Resources Assoc. 38(1):161-172.